The contribution of UVES@VLT to the new era of QSO absorption line studies

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Summary. We briefly review the main results obtained in the field of QSO absorption line studies with the UVES high resolution spectrograph mounted on the Kueyen unit of the ESO Very Large Telescope (Paranal, Chile).

1 Introduction

Over the past decade, our understanding of the intergalactic medium (IGM) at high redshift, $z = 2 - 5$, the main baryonic component of the cosmic web, has advanced considerably. We are now able to measure properties of the diffuse baryons, among them the temperature, metallicity, kinematics and radiation field, and obtain their distributions as functions of time, spatial scale, and density. These improvements are primarily determined by a rich amount of new high-resolution observational data (mainly from UVES at the VLT and HIRES at Keck) and by new theoretical hydrodynamical simulations, that incorporate the relevant physical processes. These two factors have determined a paradigm shift in the study of absorption line systems: they are now considered as tracers of the entire cosmic structure formation process over the cosmic history, and not simple probes of physical processes taking place at the Jeans length (see [16] for a recent review).

2 Why UVES made the difference?

The UV-Visual Echelle Spectrograph [6] is the high-resolution ($R \sim 40,000$ with 1-arcsec slit) optical spectrograph of the ESO VLT. It started operation in fall 1999. The high efficiency from the atmospheric cut-off at 300 nm to the long wavelength limit of the CCD detectors (about 1100 nm) was determinant for UVES to excel among the equivalent instruments (HIRES at Keck and HDS at Subaru, see Fig. 1). In our view, two other features contributed to the

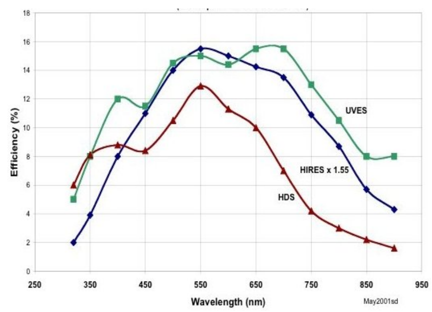

Fig. 1. Efficiency curves for UVES, HIRES (before August 2004), and HDS including telescope, instrument and detector as a function of wavelength. Courtesy of S. D'Odorico.

excellent scientific results obtained with UVES: the dedicated data reduction pipeline [3], working since the beginning of operations, and the availability of observed data in the public archive of ESO which, in the specific case of the data rich QSO spectra, allowed different users to 'squeeze' all the possible science out of them.

3 The IGM probed by single lines of sight

A remarkable contribution to the study of the IGM with the Ly-α forest was given by the ESO Large Programme (LP) "Cosmic Evolution of the IGM" [4]. A sample of 19 QSO spectra at $R \sim 45,000$ with $S/N \sim 35$ and 70 per pixel at 350 and 600 nm, respectively, was collected covering the Ly-α forest between $z \sim 1.7$ and 3.5. Data were immediately released to the public and, as of August 2007, they were used in 29 refereed publications generating 658 citations in 3 years[3].

The following important results were obtained using this sample. The investigation of the metal content of the low density IGM with the "pixel optical depth statistics" (see details in [1]), to discriminate between early and late enrichment scenarios. Metal ions are detected down to the mean cosmic density, but the information in the under-dense regions, which is critical for the studied issue, is still poor (see Fig. 3 and [2]). The nature of the Ly-α forest was exploited to compute the transmitted flux [14] and the dark matter power spectra, allowing to tighten the values of the cosmological parameters derived from the CMB [26]. The statistical and physical properties of Ly-α (e.g. [13, 21]) and C IV (e.g. [22]) absorbers were refined and assessed.

Another topic that was extensively investigated with UVES spectra was the time-variability of fundamental constants (see the contribution by P. Molaro to these proceedings).

[3] Source: "Telescope Bibliography" maintained by the ESO Library

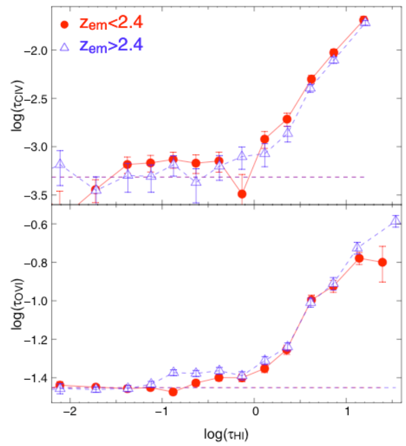

Fig. 2. C IV (top panel) and O VI (bottom panel) optical depth plotted versus the H I optical depth for the LP QSO sample (from [2])

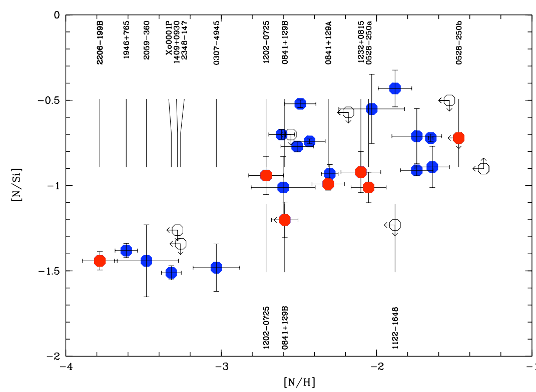

Fig. 3. [N/α] ratio as a function of Nitrogen abundance for DLA absorbers (from [9])

4 High redshift galaxies traced by Damped Ly-α systems

Damped Ly-α systems (DLA) are the quasar absorption line systems with the highest H I column densities ($N(\mathrm{HI}) > 2 \times 10^{20}$ cm^{-2}) and they arise in galactic disks or halos. They are invaluable tools to study the chemical abundances in the interstellar medium of objects in the very young Universe.

At present, there are more than 60 QSO spectra with a DLA available in the ESO public archive. Some of the notable results obtained in this field are: the estimate of the temperature of the CMB radiation at $z > 2$, which is in agreement with the hot Big Bang cosmology predictions [23, 17]; the hints on the nucleosynthesis of Nitrogen in young objects (see Fig. 3, [5]), the

properties of molecular hydrogen in DLA [15, 24, 20], and the star formation histories of individual DLA absorbers [7, 8].

The contribution of the sub-DLA population (N(HI $\geq 10^{19}$ cm^{-2}) to the total HI gas mass and to the missing metal problem was also investigated [18, 19].

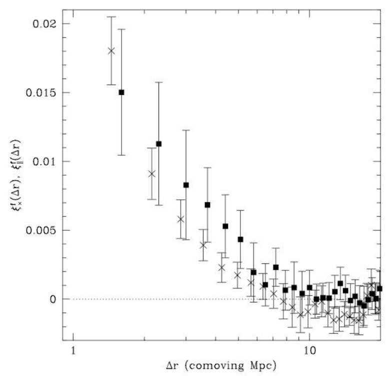

Fig. 4. Comparison of the cross-correlation function for the sample of QSO pairs (squares) with the auto-correlation function computed for the LP QSO sample (crosses) as a function of comoving spatial separation across and along the line of sight, respectively. The cross-correlation function is slightly shifted in Δr for clarity (from [11]).

5 The tomography of the IGM

To reconstruct the 3D distribution of diffuse matter with its physical and chemical properties and investigate the small-scale IGM-galaxy interactions, many high-redshift bright sources, close in the sky, are needed to use as background lights for spectroscopic studies. Several QSO pairs and groups were identified by the recent large surveys (2dFQRS, SDSS), however, most of them are too faint to be observed with UVES ($V > 18$).

A great effort was put in collecting a statistically significant sample of UVES spectra of close QSO pairs that was used to investigate the transverse clustering properties of strong metal absorbers [10] and of the transmitted flux in the Ly-α forest [11]. The agreement of the transmitted flux correlation functions along and across the line of sight (see Fig. 4) implied that distortions in redshift space due to peculiar velocities are small (< 100 km s^{-1}) and confirms the validity of the concordance cosmological model.

6 Future perspectives

In the second half of 2008, first light is planned for X-shooter at the VLT [25]: a single target, intermediate resolution (5000 at UVB and NIR, 7000 at VIS for 1 arcsec slit) wide wavelength range (UV to K bands) spectrograph. This instrument was conceived to study QSO pairs and groups and will finally allow to carry out the Alcock-Paczyǹski test, sensible to the cosmological energy content (e.g. [12]). For the next decade, two new spectrographs are under study: CODEX at the ELT (see the contribution by J. Liske to these proceedings) and its precursor at the VLT, ESPRESSO (see the contribution by L. Pasquini to these proceedings). They will be characterised by a very high resolution ($R \sim 150,000$), high efficiency, high stability and new design concepts. A second revolution in QSO absorption line studies is approaching fast!

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